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Research Article

Accumulation of trace metals in tissues of the Oriental river prawn *Macrobrachium nipponense* (Arthropoda, Crustacea, Decapoda, Palaemonidae) from polluted waters in southwestern Ukraine

Anastasiia Lepekha[1], Oleksandr Koshelev[1], Carol A. Stepien[2,3], Yuriy Kvach[1]

1 *Institute of Marine Biology, National Academy of Science of Ukraine, Italiyska St., 37, 65048 Odesa, Ukraine*
2 *Center for Global Change and Earth Observations, Michigan State University, East Lansing, MI 48823, USA*
3 *Carolina Environmental and DNA Analytics, LLC, Castle Hayne, NC 28429, USA*

Corresponding author: Anastasiia Lepekha (makiiash1@gmail.com)

Abstract

We report on the bioaccumulation of trace metals (Mercury-Hg, Copper-Cu, Cadmium-Cd, Lead-Pb) in tissues of the invasive Oriental river prawn (*Macrobrachium nipponense*) sampled from three water body areas in southwestern Ukraine: (sampling site 1) Sukhyi Lyman, (2) Cuciurgan Reservoir, and (sites 3-4) two locations in the Danube delta. Results are consistent with the hypothesis that the absorption of microquantities of trace metals from water by hydrobionts primarily depends on the relative concentration of each element. The higher its respective dissolved concentration, the higher is the metals corresponding absorption by the prawn. Our study showed that trace metal contamination of the prawns did not exceed either the national (Ukraine) or the international standard levels for crustaceans. In terms of chemical contamination, all water areas appear to meet present-day Ukraine and International guidelines for Oriental river prawn aquaculture and/or its commercial harvesting. However, given the present levels and ongoing potential for additional trace metal contaminations, and accompanying or currently unassessed pollutants, as well as their likelihoods of complex chemical, biological, and ecosystem interactions, accelerated by anthropogenic unknowns as the Russia-Ukraine War drags on, extreme caution is warranted for aquaculture, commercial fishing, and recreational harvest of the Oriental river prawn as well as other seafood species in Ukraine's waters.

Key words: Bioaccumulation, decapods, ecosystem services, human impact, pollution, toxicity

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Introduction

Trace metals, i.e., mercury (Hg), lead (Pb), copper (Cu), and cadmium (Cd), are some of the most dangerous pollutants recognized in aquatic ecosystems today (Rainbow 2002; Tchounwou et al. 2012; Nnaji et al. 2023), especially in areas undergoing high anthropogenic impacts (Kvach et al. 2025). Contamination of seafood with trace metals poses significant human health risks, as well as having long-term environmental persistence and undergoing bioamplification in food chains (e.g., Afanasyev 2023; Vyshnevskyi et al. 2023; Kvach et al. 2025). Be-

ing largely resistant to decomposition, trace metals frequently accumulate in the environment, building up in the sediments, and then can serve as a long-term reservoir leading to additional contaminations of adjacent waters and wetland areas during storms, dam breakages, dredging, and other disturbances for decades and centuries to come (see Moore and Ramamoorthy 1984; Qiu 2015; Kvach et al. 2025). Their long-term environmental persistence and spread throughout the environment leads to their accumulation and biological amplification across pelagic, benthic, aerial, and terrestrial food chains, thereby affecting the quality of aquacultural and other fisheries goods consumed by animals and humans (di Bella et al. 2021; Emenike et al. 2022; Ke et al. 2024; Bat et al. 2025).

Achieving a more sustainable system of natural resource use in aquatic ecosystems includes conserving the water basins and their native (indigenous) populations, minimizing anthropogenic impacts, and improving ecosystem services (Kaus et al. 2017; Vilà and Hulme 2017; Manfrin et al. 2019). Determining trace metal accumulations and redistribution patterns among water, bottom sediments, and aquatic fauna provides fundamental data for assessing environmental health both in the long- and the short-term.

Most studies of trace metal contamination and accumulation in aquatic organisms have focused on native species to date (Gbaruko and Friday 2007; Basset et al. 2017; Yigit et al. 2018; Manfrin et al. 2019). However, the overall effects of trace metals and other pollutants on invasive (a.k.a. alien or nonindigenous) species and their overall communities may significantly surpass those of native species due to the former's often-rapid population growth and community-level dominance, along with their tendency for rapid spread to new geographic areas (Matthews et al. 2015; Spyra et al. 2019; Tshithukhe et al. 2021; Bat et al. 2025).

Trace metals and ecological concerns in aquatic habitats and species

Benthic aquatic organisms, e.g., decapod crustaceans, often have higher levels of trace metals in their tissues than do other pelagic/planktonic organisms or the early life stages of those crustaceans (i.e., larvae) (Zauke and Schmalenbach 2006; Raknuzzaman et al. 2016; Anani and Olomukoro 2018; Casanueva-Marenco et al. 2024). It follows that the study of their trace metal content in tissues of commercially important decapod species is important for effective fishery and environmental resource management.

Alien species traditionally have been widely used for fish farming and aquaculture throughout much of the world (Lin et al. 2013; Copp et al. 2014; Gozlan 2017; Stepien et al. 2019). Among the myriad negative factors affecting aquaculture facilities and the quality of their seafood products include: pollution from trace metals, personal hygiene products, persistent organic pollutants, microplastics, and pharmaceuticals, which have been the subjects of extensive research in recent years (Sanderson et al. 2004; Baresel et al. 2015; Brázová et al. 2015; Pravdová et al. 2021, 2022; Bat et al. 2025). Whether and how such pollutants affect alien species used for aquaculture less, more, or equal than native aquacultured species, is unknown. However, many alien species tend to be more adaptable and are relatively more resistant to pollutants, pathogens, parasites, and/or environmental fluctuations than are native species, which is believed to be linked to factors governing their successes as invaders (see examples and discussions by

Karsiotis et al. 2012; Fedorenkova et al. 2013; Marshall and Stepien 2019, 2020; Stepien and Niner 2020; Morisette et al. 2021; Niner et al. 2021; Dobrzycka-Krahel et al. 2023; Marshall et al. 2024; Kvach et al. 2025; Thieltges et al. 2025).

Biology and distributional ranges (native and introduced) of the Oriental river prawn

The Oriental river prawn *Macrobrachium nipponense* (De Haan, 1849) (Arthropoda: Crustacea: Decapoda: Palaemonidae) is a Far-Eastern Asian species whose original natural distributional range encompasses deltaic zones and lower riverine reaches of Japan, Korea, Taiwan and China in the North, to Vietnam and Myanmar in the South (Chen et al. 2017; Aye 2020; Nekrasova et al. 2024). Recent introductions of the Oriental river prawn have been described in the Middle East (De Grave and Ghane 2006; Salman et al. 2006; Gorgin and Sudagar 2008; Pourgolami et al. 2021) and North America (Procopio and Daniel 2024). In Europe, this species has been recorded in Bulgaria (Kutsarov et al. 2025), Germany, Hungary (Bláha et al. 2025), Moldova (Munjiu et al. 2023), Romania (Surugiu 2022), Spain (de Carvalho-Souza et al. 2025), and Ukraine (Zhmud et al. 2022).

In Ukraine, the first Oriental river prawn population became established in the 1980s in the Cuciurgan Reservoir (our sampling site 2; Fig. 1) in the Dniester River Delta (Vladimirov et al. 1989). In the 2010s, the prawn expanded its range in the Dniester Delta and estuary region (Stepanok 2014). During the present decade (2020s), it also has been observed in numerous water bodies of southwestern Ukraine, including the Dniester and Danube river basins, and nearby small isolated drainages (Zhmud et al. 2022; Bushuiev et al. 2023; Nekrasova et al. 2024; Lepekha et al. 2025).

The Oriental river prawn characteristically inhabits clean, fast-flowing waters of pH 6.5–7.5 and temperatures of 20–28 °C, and salinities from 6–12‰ (Chen et al. 2015). Its Ukrainian populations of have planktonic larvae that survive in salinities of 3–10‰ (Lepekha et al. 2023), which may be slightly less than that of the adults (see euryhaline adaptation discussion in Dobrzycka-Krahel et al. 2023). Thus, the larvae and the adults likely occupy slightly different ranges and may differ in their dispersal extents (see examples for various crustacean species in Carbonell et al. 2021; Hiraga et al. 2021; Dobrzycka-Krahel et al. 2023).

Aquaculture, harvest, and toxicological concerns for the Oriental river prawn

Within its natural native range, the Oriental river prawn is both a commercially wild-harvested and an aquaculture species, highly valued for its taste qualities (Kutty and Weimin 2010; Hongtuo and Jin 2018). In its non-indigenous Ukraine range, it likewise has high appeal both as a commercial fishery in the wild and as a potential aquaculture species (Bushuiev et al. 2023; Lepekha et al. 2023; Nekrasova et al. 2024). Aquaculture of this species in Europe may be possible in areas where stable populations of this species have already been established in the wild (Nekrasova et al. 2024), taking advantage of potential local adaptation in for a localized adaptative brood stock to be used either in enclosed facilities or ones in natural waters (such as aquaculture pens, flow-through systems, etc.) (Hongtuo and Jin 2018; Nadarajah and Eide 2019).

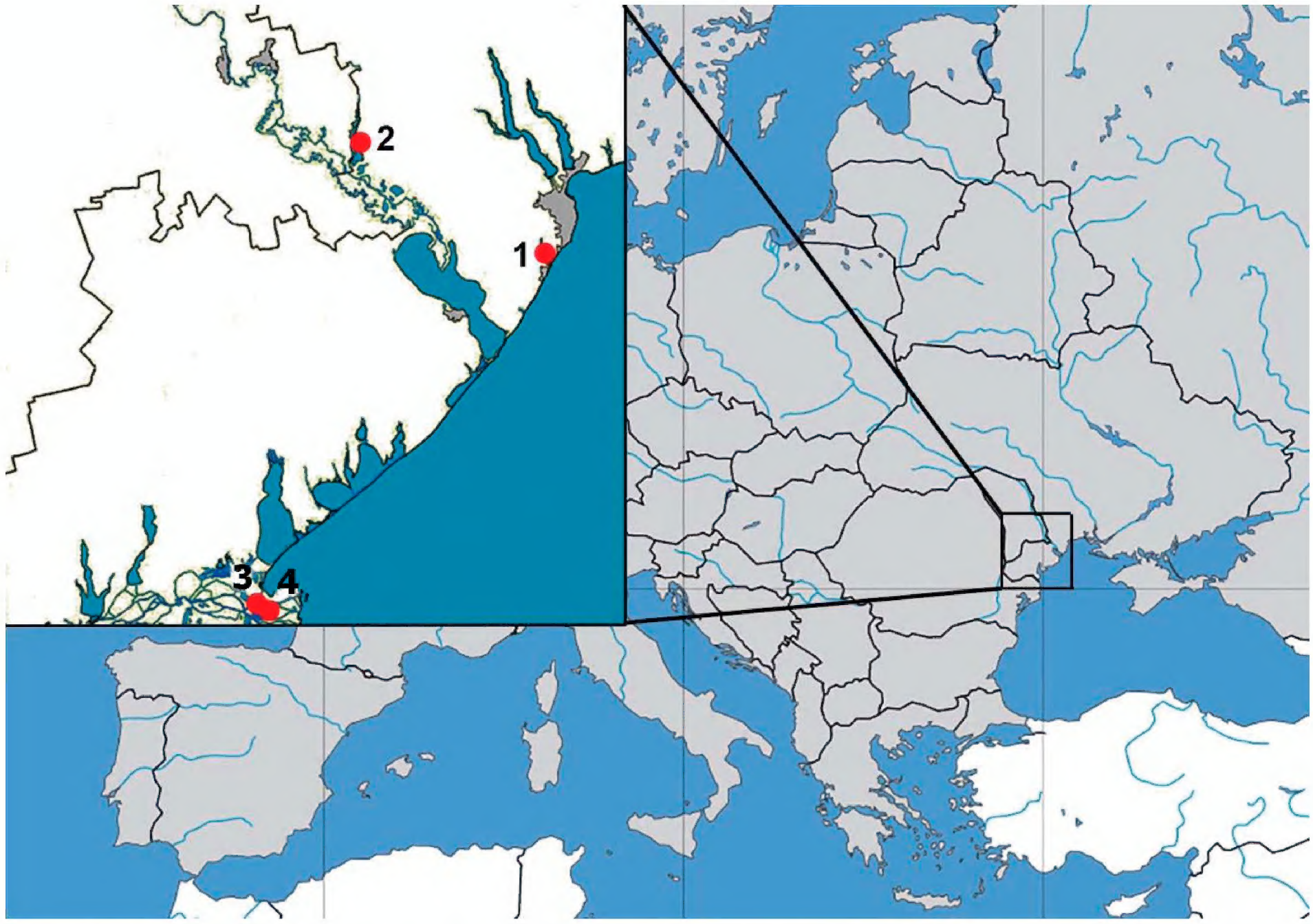

Figure 1. Schematic map showing the sampling locality regions (red circles, labelled 1-4) in southwestern Ukraine.

In southwestern Ukraine, the prawns attain significantly larger sizes in freshwater habitats than in brackish water estuaries, with the largest-size individuals reported from the Lower Danube River area (Lepekha et al. 2025; Zorina-Sakharova et al. 2025) (our sampling regions 3–4). This Lower Danube area appears well-suited for the development of its potential commercial fishery (Bushuiev et al. 2023; Dem'yanenko et al. 2025; Lepekha et al. 2025). In 2025, the commercial stock of the Oriental river prawn in the Ukrainian sector of the Danube River, was estimated as 650 tonnes, and has been predicted to increase in 2026 and beyond (Dem'yanenko et al. 2025).

Due to the Oriental river prawn's commercial importance and potential use in aquaculture in southern Ukraine, our focus here is to measure, analyze, and compare the trace metal compositions and concentrations within and among: (a) the prawn's tissues, together with bioaccumulation, (b) environmental water and benthic sediment samples from their habitat areas, (c) regional and sampling site locations from representative water bodies (sampling sites 14); additionally, we further (d) assess the possible risks of the prawn's use as a commercial human food.

Study aims, approach, and hypotheses

Our aim is to begin to assess the potential of water and benthic sediments for harboring levels of trace metals that might impact the present and future of safe aquaculture and/or commercial fishing harvest of the Oriental river prawn in southeastern Ukraine, given the past, present and likely future anthropogenic

effects and interactions in these watersheds. Among toxicological measurements used here to assess and compare the water, sediments, and Oriental river prawn tissues, the bioconcentration factor (BCF) is used to measure the chemical uptake from the water only, whereas the bioaccumulation factor (BAF) measures uptake from both the water and in the aquatic organisms (i.e., the Oriental river prawn) living in the aquatic ecosystem (Arnot and Gobas 2006). This makes BAF a more complete, ecologically realistic indicator of a chemical's total burden in the living organisms, especially for highly hydrophobic substances for which dietary intake (here of the trace metals) is significant. BCF is a laboratory measure of direct uptake, whereas BAF reflects real-world exposure, often leading to higher values for persistent pollutants in food webs (see Arnot and Gobas 2006; Mackay et al. 2018). For example, methylmercury as an environmental trace metal presents one of the greatest health risks (Clarkson and Magos 2006: UNEP 1013), and both BDF and BAF are important to determine its short-and potential long-term effects, as evaluated here in our study.

Our overall working long-term hypothesis is to test and evaluate whether the trace metal and other contaminant levels likely will remain the same in the future as today (the null hypothesis), or increase (an alternative hypothesis), given past, present and future anthropogenic stressors, with the latter including the ongoing Russia-Ukraine War (see summary by Kvach et al. 2025). Our overall long-term objective is to add to the growing body of ecological knowledge to begin to understand (a) the complex biochemical and environmental interactions among aquatic pelagic and benthic habitats, their biota, and their stressors, (b) their terrestrial and potentially aerial spread and exchanges with the aquatic environments, as well as (c) the roles and influences of native versus nonindigenous species (here the Oriental river prawn) in these processes.

Materials and methods

Sampling and localities

Three different locations in southwestern Ukraine were selected as sampling sites, which each have prospects for commercial fishing use and/or aquaculture development of the Oriental river prawn, *M. nipponense* (see Bushuiev et al. 2023; Lepekha et al. 2023, 2025). The variability of the hydrological and hydrochemical parameters of the sites were also assessed from samples collected in the warm season (May-June) of 2024 (Fig. 1):

1. Sukhyi Lyman (the estuary of the Akkarzhanka and Dalnyk rivers): 46.393778, 30.633472
2. Cuciurgan Reservoir (Dniester River drainage): 46.673250, 29.967278
3. Danube Delta (a canal in Vylkove): 45.410667, 29.605750
4. Danube Delta (Ochakiv Branch): 45.392936, 29.612353

The last two sampling sites (3–4) were considered as a single location, but differ in their hydrological indicators. Sampling depths at all sites were 1–1.5 m. At each, 1 litre of water and 200 ml of bottom sediments were collected in clean, sterile containers. Water salinity was measured directly at the sites using a conductometer (Sanxin Model SX-650 Pen Type).

Prawns were sampled using 6 mm mesh fyke-nets. From localities 1–3, five individual prawns, 1 L of water and 100 mg of sediment were sampled. In addition, five individual prawns were collected from site 4 to compare the trace metal contents in their abdominal muscle tissue from different location sites within the Danube delta region of site 4. All samples were placed on ice and transported to the laboratory; then all were frozen at –40 °C.

Analyses of trace metals

The concentrations of the trace metals in water, bottom sediments, and Oriental river prawn tissues were measured using atomic absorption spectrophotometry in the certified laboratory of Water Hygiene and Ecology of the Ukrainian Research Institute of Transport Medicine (https://open.coki.ac/institution/032x-a9n69/). Tissue samples were digested in 5 ml of concentrated nitric acid (HNO_3) at 135 °C for 4 h. Then, 1 ml of hydrogen peroxide (H_2O_2; 30%) and 1 ml of concentrated perchloric acid ($HClO_4$) were added; the solution's temperature was maintained at 150 °C until it became clear and any particles turned white or grey (Zhou et al. 1998). The resulting solution was filtered and diluted to 25 ml with ddH2O. To avoid possible contamination, all glassware and equipment were acid-washed. All calculations used wet weight (mg).

Analytical measurements were determined for the following trace metals: Hg, Cu, Cd, and Pb, with each measurement performed as five analytical replicates.

Bottom sediment contamination was assessed using the following trace metal concentration factors per Arnot and Gobas (2006):

the bottom concentration factor (BCF) was calculated using the formula:

$$BCF = \frac{Cbs}{Cw}$$

where: C_{bs} – concentration of this trace metal in the bottom sediments, mg/kg; C_w – concentration of the trace metal in the water, mg/L;

the bioaccumulation factor (BAF) was determined by:

$$BAF = \frac{Cb}{Cw}$$

where: C_b – concentration of the trace metal in the body of the prawn tail tissue, mg/kg; C_w – concentration of the trace metal in the water, mg/L.

The data were processed using standard variational statistics (StatSoft, Inc. (2014). STATISTICA, version 12. www.statsoft.com. 64). The concentrations of trace metals in the water, sediment, and Oriental river prawn tissue samples were assessed according to the following standards set by the Ministry of Health of Ukraine (2024). The obtained values then were compared with the maximum permissible concentrations (MPC) of trace metals recommended for fish farming reservoirs and for commercial crustacean tissues (FAO 2003; Ministry of Health of Ukraine 2024).

Results

The bottom sediments at all stations were composed of black silt. The concentration of dissolved soluble oxygen in the water samples indicated normal levels (>4 mg/L) at all sampling points. The salinity/mineralisation gradient

ranged from fresh water conditions in the Danube Delta (sites 3 and 4) to brackish water in Sukhyi Lyman (site 1) and Cuciurgan Reservoir (site 2) (Table 1). The analytical measurements revealed a significant difference between the total content of trace metals in the water samples versus in the sediment samples (Table 2, Figs 2, 3).

Trace metal concentrations in the water samples

The total trace metal values in the surface water samples (sampling station sites in regions 1–4) are shown in Fig. 2. Mercury levels in the water samples were twice the permissible MPC level (0.01 µg/L) in Sukhyi Lyman (site 1) and the Cuciurgan Reservoir (2) and (both 0.02 µg/L). The total concentration of copper was within the allowable Fisheries MPC (1 µg/L) in the Sukhyi Lyman (2) and the Danube Delta (3, 4), while in the Cuciurgan Reservoir (2), the levels were more than three times greater than the MPC (3.6 µg/L). The concentration of lead did not exceed the established MPC for fisheries, for all samples evaluated. Samples having the highest lead concentrations occurred in the Sukhyi Lyman (1) and Cuciurgan Reservoir (2); these sites also had the highest mercury concentrations and the latter had the highest amount of copper.

Significant cadmium contamination levels (24.5 µg/L) were detected in the Sukhyi Lyman surface water samples (site 1), exceeding the established quality standard level for fish farms (5 µg/L) by almost five times. At the remaining station sites, cadmium concentrations were below the regulatory limit: 4.42 and 0.92 µg/L in the waters of the Cuciurgan Reservoir (2) and in the Danube Delta (3,4), respectively.

Trace metal concentrations in the bottom sediments

In bottom sediments, the highest mercury concentrations were recorded at Sukhyi Lyman (site 1) (8.35 µg/kg) (Fig. 3). Mercury concentrations measured in the Danube Delta (3,4) were equal to the MPC in the water samples, while they were an order of magnitude higher in the bottom sediments than in the water. The higher levels of mercury in the bottom sediments, can then serve as a "reservoir" for exchange with dissolution in the water as sediments re-surface and are stirred up during anthropogenic and natural processes.

Table 1. Average lengths (mm) and weights (mg) of the Oriental river prawn (*Macrobrachium nipponense*) samples per sampling location (sites 1-4) and the primary water parameter measurements at those locations: temperature (°C), salinity (‰), and dissolved oxygen (mg/L).

Locality	Length-weight parameters of the prawns		Water parameters		
	Length, mm	Weight, mg	T, °C	S, ‰	O_2 (mg/L)
1. Sukhyi Lyman	45.01 ± 2.27	0.90 ± 0.20	21.7	4.2	7.2
2. Cuciurgan Reservoir	45.78 ± 2.11	0.91 ± 0.09	22.8	2.5	7.4
3. Danube (Canal in Vylkove)	48.49 ± 0.99	1.01 ± 0.13	23.1	0.2	8.1
4. Danube (Ochakiv Branch)	41.88 ± 1.56	0.57 ± 0.22	–	–	–

Table 2. Mean trace metal concentrations (µg/L) in surface waters and bottom sediments, and in the abdominal tissues of the Oriental river prawn (*Macrobrachium nipponense*) (µg/kg) at sampling sites (1-4).

Sample	Trace metal	(1) Sukhyi Lyman	(2) Cuciurgan Reservoir	Danube Delta	
				(3) Canal in Vylkove	(4) Ochakiv Branch
Surface water	Hg	0.026 ± 0.003	0.023 ± 0.001	0.016 ± 0.001	–
	Pb	17.00 ± 1.73	19.00 ± 2.00	3.00 ± 0.00	–
	Cd	24.48 ± 2.28	4.42 ± 0.32	0.92 ± 0.14	–
	Cu	1.50 ± 0.10	3.60 ± 0.26	1.50 ± 0.10	–
Bottom sediments	Hg	8.350 ± 1.008	0.075 ± 0.003	1.050 ± 0.091	–
	Pb	7260.0 ± 612.33	1210.00 ± 122.39	1700.00 ± 135.93	–
	Cd	442.91 ± 33.79	612.57 ± 56.24	1054.20 ± 4.84	–
	Cu	5708.90 ± 433.30	2154.90 ± 236.89	18189.5 ± 1430.0	–
Prawn tissues	Hg	0.466 ± 0.037	0.042 ± 0.003	0.124 ± 0.007	10.197 ± 0.670
	Pb	93.0 ± 8.19	271.00 ± 44.19	151.00 ± 14.00	157.00 ± 21.79
	Cd	185.78 ± 28.69	247.03 ± 25.79	227.40 ± 16.43	140.79 ± 11.43
	Cu	5707.8 ± 374.7	18282.1 ± 1577.9	10758.1 ± 749.4	655.0 ± 23.9

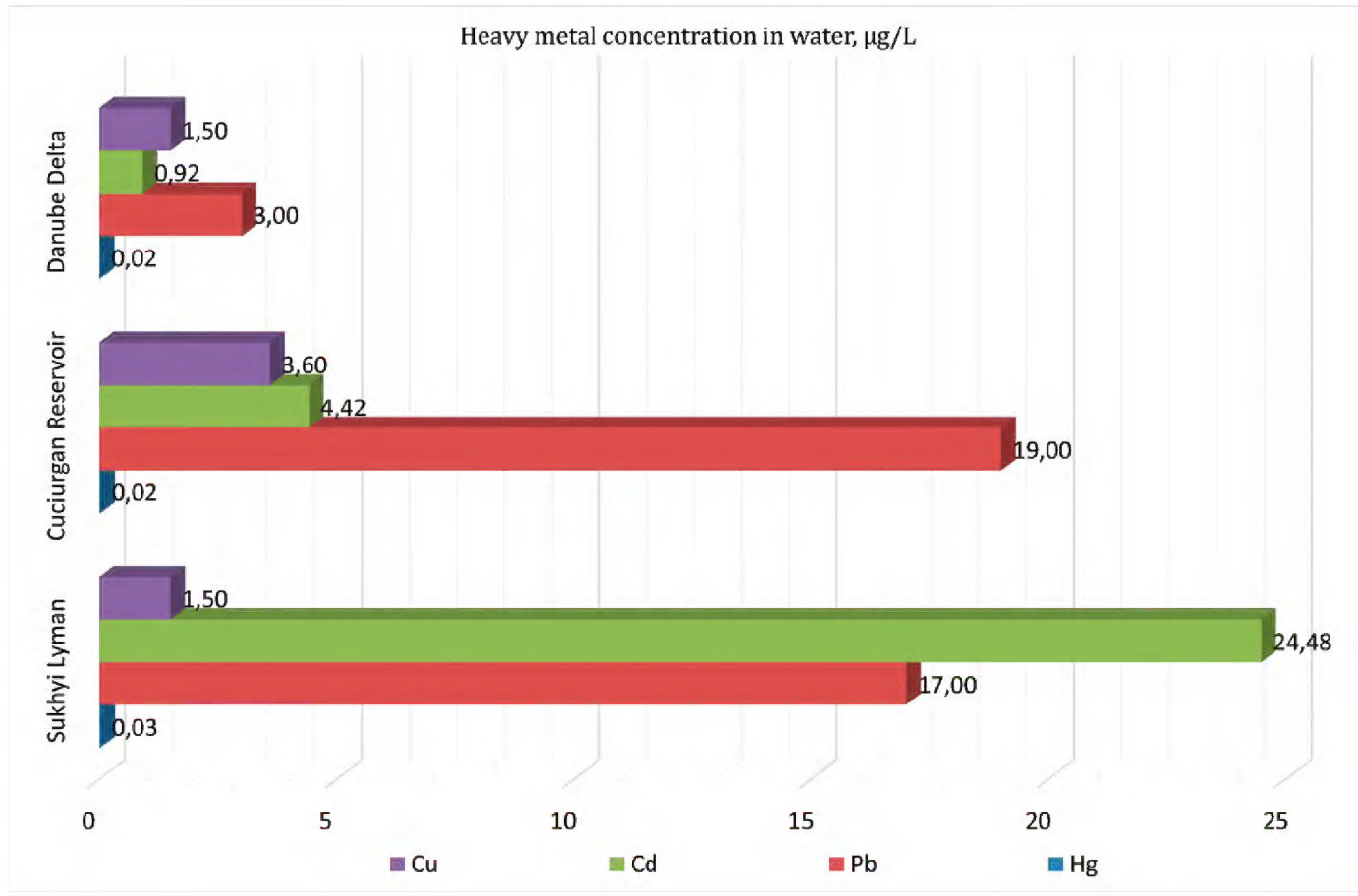

Figure 2. Content of heavy metals (µg/L) sampled in surface waters from the major sampling areas (1-3). Number the sites 1-3 as in the paper.

The highest copper concentration in the bottom sediments (18189.5 µg/kg) occurred in the Danube Delta region (sites 3,4). Copper concentrations in the bottom sediments from the upper Sukhyi Lyman (1) were 5708.9 µg/kg, whereas in the Cuciurgan Reservoir (2) the levels were minimal (2154.9 µg/kg) compared to the other samples.

Analyses revealed the following trace metal level findings in the bottom sediments: the highest concentrations were for copper (maximal 18189.5 µg/kg in the Danube channels in Vylkove (site 4), while the lowest were for mercury and then for cadmium (at all sampling localities).

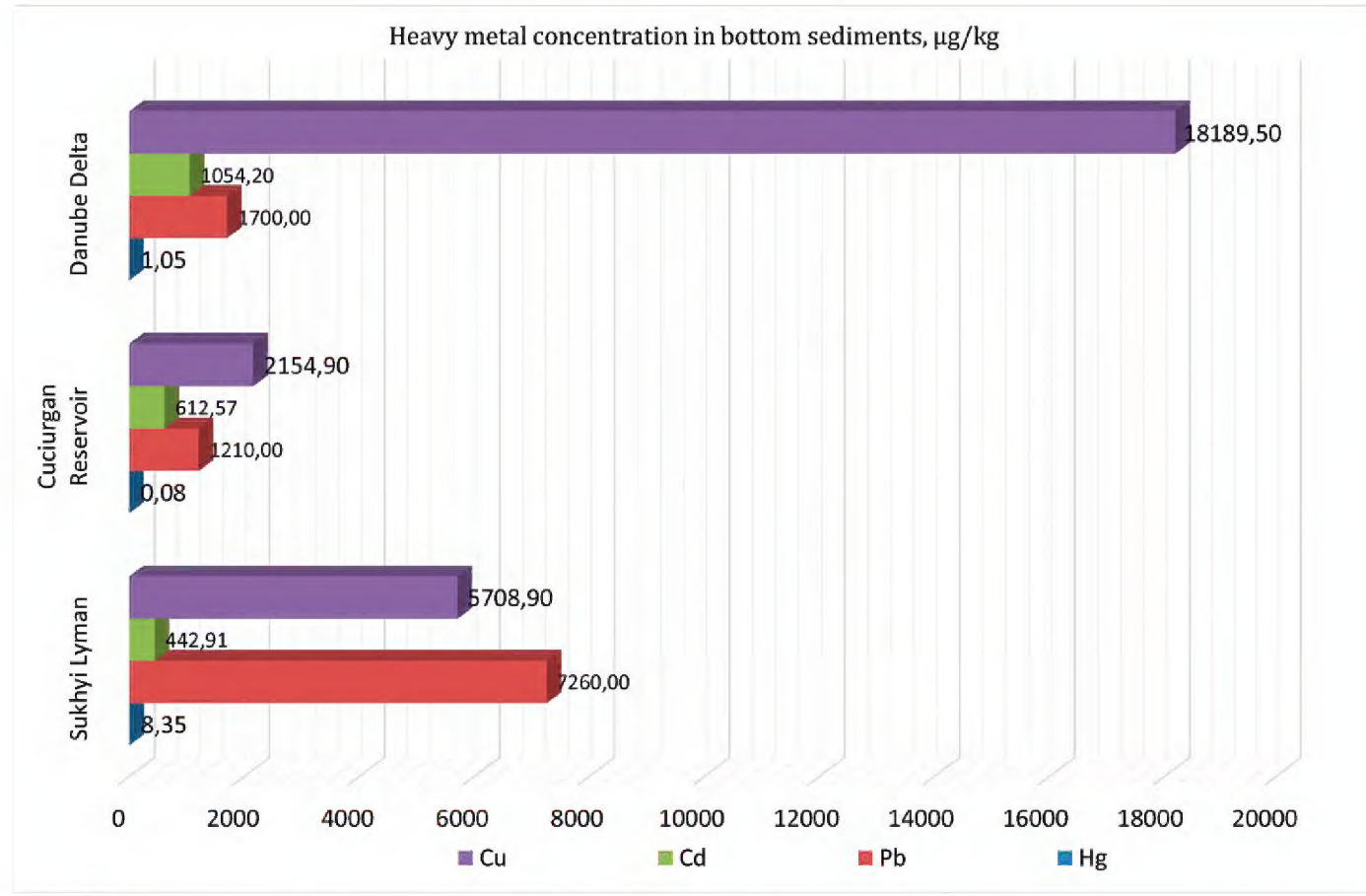

Figure 3. Concentrations of heavy metals in the bottom sediments (µg/kg) from the major sampling localities (1-3). Number the sites 1-3 as in the paper.

Trace metal concentrations in the Oriental river prawn's tissues

The sizes and weights of the prawns assessed and the hydrological parameters of the water samples (sites 1–4) are in Table 1. In terms of trace metal accumulation by the Oriental river prawns (Fig. 4), the highest values were for copper, which significantly exceeded the corresponding water concentrations in all samples. The most accumulated copper occurred in the prawns caught in the Cuciurgan Reservoir (site 2).

To compare the trace metal concentrations in prawns taken from different water bodies and sampling areas, the accumulation coefficient indicators were analysed in comparison to both the water and bottom sediments. The total trace metal concentrations in the prawns were similar among all sites. Likewise, environmental measurements among sites 1–4 were similar for the water and for the sediment conditions. Higher levels overall in the sediments than in the water, indicated intensive accumulation of pollutants (Table 3).

The highest copper accumulations in both the bottom sediments and the prawn tissues occurred in the Danube channels in the City of Vylkove (site 3), recorded as: 7,172.06 (BAF) and 12,126.33 (BCF). In the Cuciurgan Reservoir (2), the accumulation coefficient exceeded the bottom accumulation coefficient by almost 8.5 times, while in the Sukhyi Lyman (1), these coefficients were statistically similar. Among the trace metals analyzed, the highest accumulation coefficient values were found for copper. These reached the highest levels in the channels of Vylkove (site 3) and the lowest in the upper reaches of the Sukhyi Lyman (1).

Discussion

The study results show that the water areas examined did not exceed either the established international and/or Ukraine's national standards for trace metal contamination in crustacean tissues, relevant to the safe harvest

Table 3. Indicators of heavy metal accumulation, measured as the Bottom concentration factor (BCF) and the Bioaccumulation factor (BAF) from bottom sediment and abdominal tissue samples of the Oriental river prawn (*Macrobrachium nipponense*) at sampling locations (1-4).

Locality	Hg	Pb	Cd	Cu
Bottom concentration factor (BCF)				
1. Sukhyi Lyman	321.15	427.05	18.09	3,805.93
2. Cuciurgan Reservoir	3.26	63.68	138.59	598.58
3. Danube Delta	65.62	566.66	1,145.86	12,126.33
Bioaccumulation factor (BAF)				
1. Sukhyi Lyman	17.92	5.47	7.58	3,805.2
2. Cuciurgan Reservoir	1.82	14.26	55.88	5,078.36
3. Danube Delta	7.75	50.33	247.17	7,172.06

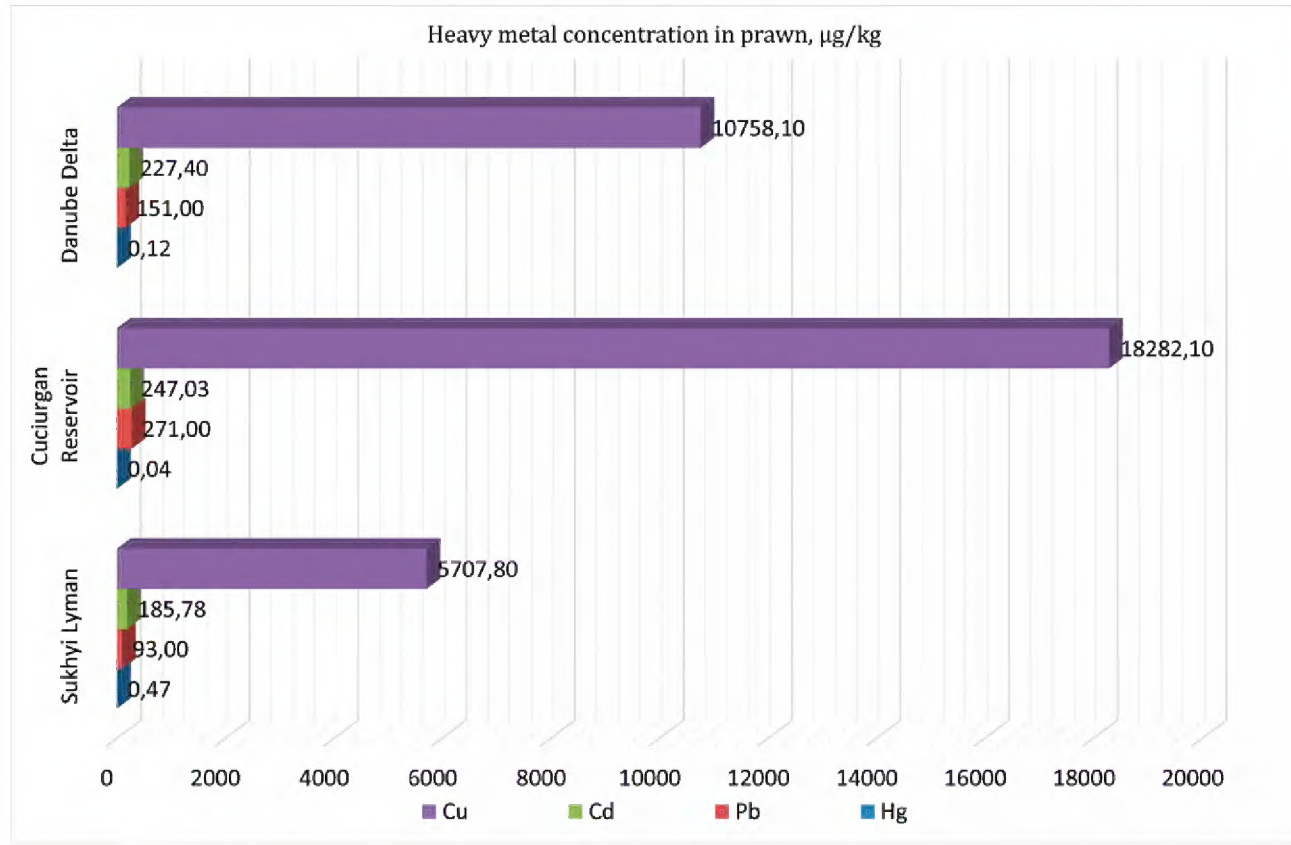

Figure 4. Content of heavy metals in tissues of the Oriental river prawn (*Macrobrachium nipponense*) (µg/kg) from different sampling localities. Number the sites 1-3 as in the paper.

of the Oriental river prawn. To ensure food safety and assess the potential risks posed by trace metal contamination to human health, the Food and Agriculture Organisation (FAO) and the World Health Organisation (WHO) have established maximum concentrations for a number of trace metals in various aquaculture products, including crustaceans (FAO 2003). According to these standards, the average concentrations of lead and cadmium in edible parts of crustaceans should not exceed 0.5 mg/kg. In Ukraine, the levels of certain contaminants in food products, in particular trace metals in crustacean meat, are determined by the Regulations on maximum levels of certain contaminants in food products (Ministry of Health of Ukraine 2024). According to these Regulations, the respective concentrations of lead, cadmium, and mercury in the meat of crustacean limbs and abdomens must not exceed 0.5 mg/kg each.

In terms of chemical contamination, all of the water areas studied here currently appear to harbor concentrations that are classified as suitable for aquaculture of the Oriental river prawn/or for its commercial harvesting (Ministry of Environmental Protection and Natural Resources of Ukraine 2021).

Our results are consistent with the premise that the absorption of micro-quantities of trace metals from water by hydrobionts primarily depends on the concentration of each particular element (Luoma and Rainbow 2008). Thus, the higher the dissolved concentration of a trace metal, the higher its absorption from the water by the body of the aquatic organism, according to our findings. Further, the concentrations of regulated trace metals in the tissues of the Oriental river prawn in southwestern Ukraine that were measured here, are much lower than the levels recorded in the other studied regions. By comparison, our concentration values for Hg (which here had the lowest of the trace metal values for the Oriental prawn in southeastern Ukraine) were much lower than those recorded for the green tiger prawn *Penaeus semisulcatus* in the Persian Gulf (the latter at approximately 80 µg/kg by dry weight, dependent upon the sampling locality) (Raissy et al. 2011; Shahsavani et al. 2017). In further comparison, trace metal levels measured in the Oriental river prawn from China (its native range) were recorded as 5486 µg/kg of Cu (the maximal allowable parameters for human consumption) and 29 µg/kg of Hg (minimal parameters) (Yu et al. 2020).

Our analyses of the accumulation coefficients indicate a significant excess of BCF over BAF, revealing accelerated trace metal accumulations in the bottom sediments from southern Ukraine's aquatic habitats compared to their levels in the biota (i.e., the Oriental river prawn tissues). Habitat areas whose sediments have high trace metal accumulation levels are potentially dangerous to human and wildlife health. High BCF values indicate that the overall concentration of a particular toxicant in the bottom sediments is much higher than its levels in the water, indicating the capability of the bottom sediments to serve as a reserve of these trace metal pollutants. The sediments are capable of releasing metals and other pollutants into the surrounding water as well as into other regions of the watershed and beyond. Such releases accelerate when physical and chemical conditions change, such as during disturbances to the sediment layers, caused by flooding, extreme weather events, dredging, and/or construction, etc.

We obtained higher BCF values for copper and lead, which were prevalent in the most polluted bottom sediments that we sampled. Notably, permanent copper contamination of the sediments likely is associated with the use of copper compounds as a plant protection product for treating the numerous vineyards in the catchment area. The results we obtained will allow managers and researchers to classify the Oriental river prawn as a species that bioaccumulates copper from its aquatic habitats in southern Ukraine. On the other hand, copper is functionally important for crustaceans, being integral for metabolism, various physiological and biochemical processes, synthesis of many important enzymes, and provides an antioxidant defence system (Chen et al. 2025). In addition, copper binds to oxygen in crustaceans' respiratory protein haemocyanin in the haemolymph, which is essential for (the prawns') respiration (Kato et al. 2020).

Despite the fact that the concentration levels of trace metals measured in the Oriental river prawn tissue samples are within the currently-acceptable levels for human health consumption, trace level pollutants were appreciable in all of our aquatic habitat sites, both in surface waters and bottom sediments. For example, the Sukhyi Lyman region (our sampling area 1) has been anthropogenically transformed from its original habitat condition into a large maritime complex, greatly accelerated during the Russia-Ukraine War (see synopsis by

Kvach et al. 2025). This area now contains ports (both for trade and commercial fisheries), a railway junction for maritime transport, and many other enterprises. Notably, such intensive anthropogenic pressure has led to the very high technogenic pollution of the Sukhyi Lyman with cadmium.

The Cuciurgan Reservoir (our region 2) has been converted into a lake-type cooling pond for the Moldovan State District Power Plant (Moldovan SDPP). A technologically important condition for the Moldovan SDPP hydroelectric complex's functioning is the regular discharge of warm water used for cooling, and the flushing (cleaning) of the station's units with various reagents, in particular acids. These discharges lead to large areas of hypoxia and acidification of the water in the Reservoir. These processes occur against the backdrop of growing eutrophication of the surrounding surface waters and alongside the permanent processes of sulphate reduction and hydrogen sulphide accumulation in the water. They then contribute to the process of reverse diffusion of metals from the benthic sludge into the water. Significant levels of trace metals in the Cuciurgan Reservoir ecosystem, which migrate with other pollutants among the water, benthos, and organisms, thus lead to their joint accumulation and bioamplification in aquatic plants, invertebrates, and vertebrates, including fishes, crustaceans, and mollusks (Philipenko 2016).

The interacting components in the Danube Delta region (our sampling areas 3 and 4) accumulate the range of pollutants that arrive from and cycle within a large catchment area (Vlasenko and Melnykov 2018; Melnykov 2018). This area possesses a wide range of biochemical and habitat conditions, and exchanges among these ecological components, habitat types, pollutants, and the biota are complex. These interactive conditions and exchanges appear to be accelerating with the current Russia-Ukraine War (see Kvach et al. 2025).

In summary, the average overall concentrations of all measured trace metals in Sukhyi Lyman (our sampling region 1) are ranked by our study as: Cd>Pb>Cu>Hg (water), Pb>Cu>Cd>Hg (bottom sediments), and Cu>Cd>Pb>Hg (Oriental river prawns). Concentration rankings for the Cuciurgan Reservoir (region 2) are: Pb>Cd>Cu>Hg (water), Cu>Pb>Cd>Hg (bottom sediments), and Cu>Pb>Cd> Hg (prawns). Those for the canals of the City of Vylkove in the Danube Delta (region 4) are: Pb>Cu>Cd>Hg (water), Cu>Pb>Cd>Hg (bottom sediments), and Cu>Cd>Pb> Hg (prawns).

Overall, given the growing pollution levels of water bodies in southern Ukraine with trace metals and other understudied substances, which may interact, caution should be exercised with regard to the possible aquaculture of the Oriental river prawn (*M. nipponense*). Continued and increased monitoring of trace metals and other pollution types and sources – at a minimum those regulated by current-day Ukrainian legislation – should be carried out. At present, scientists and managers lack access to sample many critical locations, due to the Russia-Ukraine War activities. In conclusion, these and continued data collections are essential to guarantee safety of aquaculture and fisheries for human and wildlife consumption, as well as for clean water, seafood availability, and the surrounding sustenance of agricultural resources. The study of these baseline contaminant levels, along with a myriad suite of their interacting factors and environmental exchanges, will have continuing importance for decades to come.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

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No ethical statement was reported.

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AL: sampling, species identification, conceptualization, visualization, writing review, and editing. OK: conceptualization, formal analysis, methodology, writing original draft. CAS: revision and rewriting, analysis interpretation, ecological hypotheses, writing review, and editing. YK, supervision, funding acquisition, writing review, and editing. All authors reviewed and approved the manuscript.

Author ORCIDs

Anastasiia Lepekha https://orcid.org/0009-0006-8461-7025
Oleksandr Koshelev https://orcid.org/0000-0002-8937-2323
Carol A. Stepien https://orcid.org/0000-0002-5544-4333
Yuriy Kvach https://orcid.org/0000-0002-6122-4150

Data availability

All of the data that support the findings of this study are available in the main text.

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